Vanishing Bloodstains: Determining the optimum apparel fabric and residential lighting conditions for a bloodstain to disappear

by

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List of Tables

List of Figures

Abbreviations

BPA=Bloodstain Pattern Analysis

ALS=Alternate Light Source

CST=Crime Scene Technician

Cot=Cotton

Den=Denim

Fle=Fleece

Mil=Military Uniform

Moi=Moisture Wicking

Nyl=Nylon

Poly=Polyester

Ray=Rayon

Swe=Sweatshirt Jersey

CMOS=Complimentary mental-oxide-semiconductor

IR=Infrared

ISO=International Standards Organization

Definitions

Intensity value=Refers to the amount of light, in a numerical value, for a pixel. In grey scale images it is presented on a scale of 0 (darkest) - 255 (lightest).

Contrast=The difference between the brightness and darkness of an image.

Negative Contrast=Refers to an intensity value that is negative, or an area that appears brighter than the background.

Luster=The degree of light that is reflected from the surface of a fiber, also "gloss or sheen."

Abstract

Bloodstain Pattern Analysis (BPA) is one of the most important forensic crime scene techniques to date. Fluid dynamics with blood remain relatively similar across the board, which is why many researchers remain focused on specific patterns and what they can reveal about the movements of contributors in a scene. As a bloodstain pattern analyst becomes more proficient in the identification of certain stains, the advanced analyst will begin to study the effect of blood on fabrics. It is well known within the field of BPA that Alternate Light Sources (ALS) are

required in most scenes containing blood evidence. This researcher sought to identify which specific fabrics (color and composition) best mask blood stains under residential lighting conditions.

Determining the fabric which best disguised a given blood stain will prove useful to the Crime Scene Technician (CST) as well as the subsequent litigation team. If a person alleged they observed “bloody clothing” on a subject/victim, this research answered whether this observation was possible to the untrained eye. Additionally, the results sought to determine the optimum fabric type, pattern, and color to best disguise blood on apparel fabric at a scene. When the “optimum fabric” was observed at a given crime scene with potential blood evidence, this research would trigger the crime scene technician to utilize an ALS, as well as submit the item for in-depth analysis at the laboratory.

A sample of fabrics was tested using recent statistics of U.S. consumption of fabric. This ensured an equal sampling of the general American population, and included various solid color and printed fabrics. Additionally, the sample fabrics included various military uniforms (Army Multicam, Marine Combat Utility Uniform, Navy Working Uniform, and Airman Battle Uniform) to make the study relevant to the Department of Defense. The various fabric types and patterns provided different qualities with the respective blood stains that were subsequently measured to gain quantitative results. The fabric samples were placed in four separate indoor lighting conditions, and the contrast of the stains were objectively measured and determined there was no significant difference between each light source. This research ultimately determined there was a significant difference between the construction and color of the fabric.

Background

Bloodstain pattern analysis can be traced back through history to the 1800's in historical German periodicals. As forensic science progressed through more frequent technological advances, the understanding of this type of evidence constantly shifted (Bevel and Gardner, 2008). Experts emerged and made claims they determined the exact events which took place on scene, from the bloodstain patterns alone. More recently, the 2009 National Academies of Science report, *Strengthening Forensic Science in the United States: A Path Forward,* established thirteen recommendations in an effort to hold the field of forensic science more accountable. Before this report, many experts overstated their opinions, which sometimes had no scientific basis. This report was a much needed wake up call to many who call themselves experts and has now created a huge push for data to support any hypothesis.

A major objective of this research was to establish a baseline method, or experimental design, to study, calculate, and quantify the effect of indoor white lighting on bloodied apparel fabrics. An established protocol would assist the crime scene examiner to determine which apparel fabrics would immediately require ALS for further investigation or if the lighting in the residence was too poor altogether.

There has been little to no research on the visibility of human blood on apparel fabrics in residential conditions. Most BPA on fabric is concerned with the interpretation of stain type on fabric (De Castro et al., 2013), effect of laundering stained fabric (De Castro et al., 2015), alternate light source detection on fabric (Schotman et al., 2015), or the reliability of BPA on stained fabric (Taylor et al., 2016). In order to understand how a stain will appear, a general understanding of the light spectrum and how light energy reacts with different surfaces was needed to conduct this research. Many entry level forensic text books related the visible light spectrum was between 400-700 nm, and white light was a combination of various reflected colors. A total reflection of all light on a surface would appear white, while the total absorption of all light on a surface would appear black (Robinson, 2016). Though the visible light spectrum seems minuscule, there is still enough nuance to assist in discovering the optimal conditions for observation. For the purposes of this research, certain light sources have output at certain wavelengths: LED emits around 550 nm, CFL emits between 540-615 nm, and incandescent emits its highest wavelength at 800 —which is outside the visual spectrum (Smith, 2016). Sliney (2016) related natural light can be anywhere from 360-830nm. These numbers were approximate and would vary depending on light temperature and intensity.

Given certain residential indoor lighting options, blood will be rendered less visible on certain fabrics, to the naked eye and to the crime scene cameras. Given this conjecture, this method focused only on the simplest blood stain type: the drip, which was described as "spatter resulting from blood dripping from an individual or otherwise bloodied object (Bevel & Gardner, 2008).

Objectives and Questions

The primary objective of this research was to determine if residential indoor lighting significantly affected the contrast of blood on common apparel fabrics. The secondary objective was to determine which common apparel fabric hid blood the most, or created the least amount of contrast. Finally, the third objective was to establish a baseline method to objectively study contrast values of blood on fabrics. These objectives are further broken down into five research questions:

Q1. What residential lighting will best mask human blood stains on apparel fabric?

Q2. Which color or patterned fabric will best mask a blood stain?

Q3. Is it more difficult to distinguish blood stains on patterned fabric of various hues than black fabric?

Q4. Which military fabric will best disguise blood in residential lighting?

Q5. Will a digital SLR camera expose blood stains better than the human eye?

Hypotheses

The above questions are further broken down into separate hypotheses.

Question 1: What residential lighting will best mask human blood stains on apparel fabric?

Hypothesis: Incandescent lighting has the lowest intensity out of all the light sources, while sunlight has a high intensity and contains IR, which extended the overall visibility of some colors under this condition. Incandescent light would create the least contrast, while sunlight would create the most contrast.

Question 2: Which color or patterned fabric will best mask a blood stain?

Hypothesis: The darkest and most absorbent fabrics would create the least contrast.

Question 3: Will patterned fabric be harder to distinguish blood stains than solid black fabric?

Hypothesis: Due to the nature of the blood pattern utilized for this research, which was a drip stain, the patterned fabric would be easier to observe contrast than the fabric's solid counterparts.

Question 4: Which military fabric will best disguise blood in residential lighting?

Hypothesis: The lightest patterned uniform (Air Force) would have the greatest contrast, while the darkest uniform (Navy) would have the least contrast.

Question 5: Will a digital SLR camera expose blood stains better than the human eye?

Hypothesis: The Nikon camera light meter corrected for the "best exposed photograph," which in most cases is not actually what the human eye observed. Under these circumstances, it was expected the camera would also provide the best contrast, as the processor in the camera is designed to work better in lower light conditions. This research was concerned about what the crime scene technician on scene could see without the aid of alternative light sources therefore an objective measurement of what the camera would "see" and what the technician would "see" is beneficial.

Literature Review/Methods and Materials

-Fabric Selection-

This study focused on the ideal color and pattern configuration for popular fabrics to conceal human blood in normal white light circumstances, thus a white control fabric was utilized for each type of fabric, a black color, as well as a patterned multi-colored sample. The researcher acknowledged there existed countless types of colors/patterns, but this research focused on three or less differing colors and a simple repeating pattern. Due to the variation, there were lighter colors in the patterns, so prior to buying the fabrics, the researcher assumed the floral patterns would mask blood the most, but after obtaining the patterned fabrics, which included lighter colors in the floral theme, the patterned fabric might cause the stains to stand out. The researcher made observations at active crime scenes that certain types of blood stains appeared to vanish on certain patterned fabrics. Testing all types of patterned fabrics would be impossible, as there are millions of variations, but for simplicity the most common floral pattern with at least three variable colors along with a dark background were chosen. Because this research involved the most widely available fabrics, or a convenience sample, the patterns and colors were not specially ordered for each type of fabric, so there were variations in the patterns.

Several market research reports for textiles listed the following products as the most popular purchased by the US market: cotton, natural-fibers, polyesters, and nylon (“Textile Market Size”, 2019). This list was cross referenced with Global Sources, which listed trends in fashion apparel and customer inquiries for the following: men’s round-neck t-shirts, women’s leggings, baby clothing sets, lingerie, shift dresses, yoga wear, men’s short sleeve polyester shirts, men’s casual jackets, evening dresses, and men’s long sleeved casual shirts (“Trends in US Textile”, 2018). This list was extrapolated into a comprehensive collection of apparel fabrics which would most commonly be encountered at a crime scene in the continental US. The researcher purchased the following apparel fabrics at Joann’s Fabric Store: polyester, rayon, rayon blend, nylon, cotton, wool, denim, sweatshirt jersey, fleece, and moisture wicking. Fabric samples not found at Joann’s were white and patterned sweatshirt material, patterned denim material, as well as multicolored moisture wicking material, and were subsequently purchased at a local Walmart. In order to make the study relevant to the Department of Defense, the researcher obtained the following American Apparel brand products: Airman Battle Uniform coat (Air Force), Multicam coat (Army), Marine Corp Combat Utility Uniform woodland coat (Marines), and Navy Work Uniform coat (Navy). All military coats were found to be constructed of 50% cotton and 50% nylon. American Apparel related Brittany International was the bulk fabric supplier for Army, Navy, Air Force, and Marine utility coats. Brittany International provided bulk “grey” fabric, which was what all the previously mentioned military uniforms consisted of prior to the color and pattern application. This sample, which was white, acted as the control for the military uniform samples.

-Composition of fabric-

A general understanding of composition and anatomical features of commercially available fabric for the consumer was necessary for any bloodstain pattern analyst when examining blood deposited on different textiles (Bevel & Gardner, 2008). This research focused on the macroscopic traits of the fabric samples, and the visibility of human blood on different colors/patterns, however, some general predictions led the researcher to a more microscopic level of observation. For this research, each fabric weave pattern was documented, which were woven, knit, and non-woven. Parrish (2016) defined woven fabric as yarns interlaced at right angles. Some general examples can be observed in denim, bed sheets, and dress shirts. Parrish (2016) further defined knit fabrics as the "inter-looping of one or more sets of yarns," commonly observed in t-shirts, sweaters, underwear, hosiery, etc (p. 17). Woven fabrics were said to be more stable, have less shrinkage and less able to stretch. Knit fabrics were less stable, had less coverage, but were capable of more stretch and more breathability. Woven production speed was also noted to be slower when compared to knit fabrics. Non-woven fabrics were defined as fiber being compressed together by mechanical, thermal, or chemical methods. Common non-woven fabrics included felt, diapers, or wool blends (Parrish, 2016).

Though the writer understood the microscopic composition of fabric, the implications did not affect the contrast of the blood on different colors/patterns. Below is a brief explanation of yarn structure which could assist the reader in understanding the making of yarn and may come into play with bloodstain patterns other than drip stains. The work conducted in Li's (2017)

"Effect of Yarn Structure on Wicking and its Impact on Bloodstain Pattern Analysis on Woven Cotton Fabric," illustrated the difference in three separate spinning techniques: ring spinning (characterized as expensive, but the oldest and most popular method, which creates uniform staple fibers), open end spinning (characterized by increased productivity and reduced cost, however, weaker and less uniform yarns, and contains a twist), and vortex spinning (characterized as the lowest cost process, most recent, and created by blowing air jets around different fibers which force them to twist around a core). Li (2017) concluded ring spinning formed round stains with irregular edges, which had the most pronounced wicking, whereas open end and vortex spinning did not wick blood, as the blood instead stayed on the surface and slowly soaked through, creating more elliptical shaped stains which could have been distorted due to the twists in the fibers. Li (2017) also related many commercially available fabrics are a combination of two methods of spinning, which would cause distortions and wicking depending on the direction and make of the warp and weft of the yarns. Li continued with the observation in all samples that the shape of the stain changed immensely during the wicking process, which makes any type of directionality or shape determination daunting to the analyst (Li et al., 2017). These observations could have potential implications in the ability to observe certain stains on patterned fabric as well. See Table 1 for a complete breakdown of each fabric color and type used in this research.

-Fabric Preparation-

Each fabric was cut into an 8x11 inch rectangle, then folded over and hemmed using an electric sewing machine (SINGER Pixie-Plus Craft Machine, Singer Sewing Company, LaVergne, TN 37086) which created samples measuring approximately 7x10 inches. There was quite a bit of research regarding the preparation of textiles for scientific testing. Most new fabrics undergo chemical washes or have oils deposited on them in preparation for retail. In order to best mimic apparel found at a crime scene, this researcher compared the most recent BPA and textile studies to find the general consensus to achieve stable samples. De Castro et al. (2015) highlighted several key observations in her article, "Systematic Investigation of Drip Stains on Apparel Fabrics: The Effects of Prior-Laundering, Fiber Content and Fabric Structure on Final Stain Appearance," which were integral to this research design. De Castro et al. (2015) found the removal of finishing treatments (chemicals/oils/starches) and stabilization of fabric happened consistently after six washes. De Castro also observed the largest physical change in fabrics occurred during the first six cycles, which indicated her samples were already dimensionally stable if washed any further (De Castro et al., 2015). Gore (2006) found drying between cycles did not affect the mass of the fabric, as previously thought, and further suggested the best dimensionally stable fabric occurred with six wash cycles, and no drying in between, then flat dried following procedure C in ISO 6330 (Gore et al., 2006). The following method of washing was created by this researcher to be as close to ISO guidelines as possible. Each sample was washed by using a General Electric home top-loading washing machine, model number WCSR2080B2WW. One half tablespoon of TIDE detergent (a registered trademark of Procter & Gamble Co., Cincinnati, OH 45217) without optical brightener was added to the washer, and the wash setting was set to medium/casual cycle (approximately 20 minutes). The water was measured to be 96 degrees F +/- 4 degrees. To best represent clothing to be encountered on scene, the researcher washed the like fabrics samples together (white fabrics, dark or black colored fabrics, patterned multicolored fabrics, and military fabrics). Each type of load was washed six separate but consecutive times. The fabrics were laid out on a flat surface to condition for 24 hours at 72-73 degrees F and 52-58% humidity. Line drying would have potentially altered the weave of each fabric and utilizing the dryer machine would have shrunk the material, which was hemmed prior to laundering to prevent fraying and loosening of fabric weave.

-Fabric Mounting-

There has been little research on different mounting methods, however, Chang and Michielsen's (2016), "Effect of Fabric Mounting Method and Backing Material on Bloodstain Patterns of Drip Stains on Textiles" was an effective starting point. They concluded if the blood is deposited onto fabric with hard backing, e.g. concrete floor, it initially reacted in a way similar to when it is deposited on non-porous and non-absorbent surfaces, like tile or hardwood, which in the researcher's opinion, almost defeated the purpose of testing the fabric. If the fabric is stretched taut, the blood may "bounce off" of the fabric and land several cm away creating more satellite patterns. Additionally, if the fabric was draped over a surface, not stretched taut, the blood will be absorbed with little to no satellite stains. Lastly, an additional fabric underneath the questioned sample, could soften the impact of the blood (Chang & Michielsen, 2016). The current study focused only on the contrast of blood on commercially available fabric, so the stain size and shape was not measured, and thus not much consideration was made in determining different backings, as only the contrast of the stain was calculated. Additionally, this research was focused on the ability to see a stain deposited on fabric only, without the added variable of different backing. So to limit satellite stains, the fabric was draped over an embroidery hoop, to elevate the fabric from any backing, and to allow the blood to interact with the fabric only. Li suggested the capillary action between a hard substrate or backing and the tested fabric was high and caused liquids to spread rapidly and alter the stain shape (Li, 2017). This research eliminated the variable of backing-caused capillary actions completely, and allowed the blood to only interact with the fabric structure and colors.

All blood drops were deposited on the technical face of each fabric sample. This was to keep consistent with what most crime scene investigator's will observe at a crime scene or on a person. Also, most previous research included photographs of the blood just after it was deposited, as well as after the blood had completely dried. This research noted specific general observations of the blood after it was deposited as it was drying, however, the focus of this research was on dried blood, so the photographs of the samples were taken 24 hours after the blood was deposited. Chang et al. noted there were significant changes to the stain between 0-10 minutes, however, it is unlikely the crime scene investigator would arrive to a scene prior to the ten minute mark (Chang & Michielsen, 2016).

-Blood Preparation-

Most research surrounding BPA focused on porcine blood, or human blood that had added anticoagulant due to restrictions from the institution the research was funded from. Those blood specimens may have unforeseen effects as the blood is deposited onto a fabric that would not normally be observed on a crime scene with human blood contributors. This researcher utilized human blood that had been drawn no more than one hour before it was deposited on the sample fabric. This was to prevent adding anticoagulant, as well as to keep the blood as close to human body temperature as possible. The blood temperature before it was deposited was 74-77 degrees F.

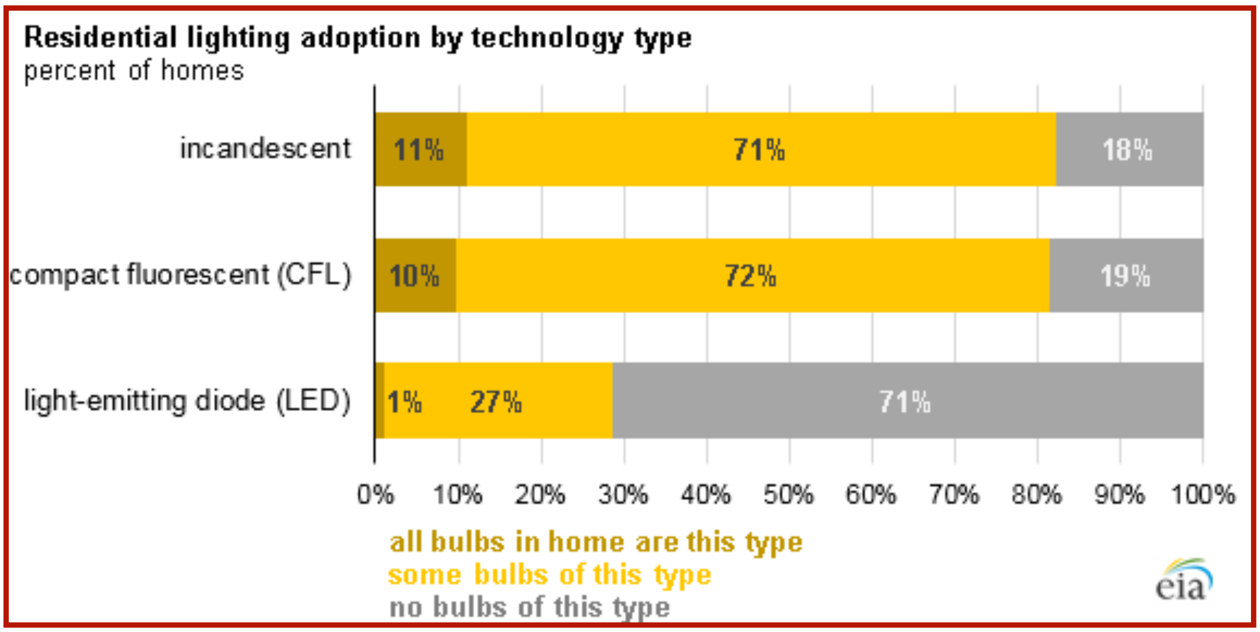
-Blood Deposit Mechanism-

A dropper was set directly 90 degrees above the fabric sample. The tip of the dropper was measured six inches from the fabric sample utilizing a telescoping stand (See Figure 1). The amount of blood deposited on each fabric sample was 1.0 mL. Velocity of the drop was not calculated. Three separate stains were deposited on each fabric sample.

-Light Sources Tested-

Different light sources taken into consideration were those most likely to be encountered in an indoor residential crime scene. As of May 2017, the U.S. Energy Information Administration provided the following population data:

Figure 2. *U.S. Energy Information, Residential Lighting Breakdown*



Note: Data for U.S. residential lighting breakdown from Woodward & McNary (2017)

Figure two related most residential housing utilized incandescent lighting (71%), however, a garage or a kitchen could utilize a combination of incandescent and CFL. As homes become more eco-friendly and energy conscious, LED lighting will become increasingly popular.

Finally, direct sunlight through a non-tinted window could also be a light source encountered on scene. To simplify extraneous properties, the sunlight light coming into an un-shuttered window was utilized while the sun was in the highest position of the day without any cloud cover.

The following is the list of all light sources utilized in this research:

Incandescent: 120V/40W LR58060 Clear light bulb Base Globe Incandescent Clear Light Steel Light Bulb

CFL: Philips Econ-o-watt F40CW/RS/EW, 34 Watt, Alto Collection

LED: 120VAC, 60Hz,5.9W,53mA (UCL/18/16/10/6/120)

SUN: South facing windows, no UV protection, between 1000-1200 in October 2019

-Camera Utilized for Documentation-

The Nikon D5500 camera utilized a Complementary Metal-Oxide Semiconductor (CMOS) sensor, which was said to be more susceptible to noise and have less light sensitivity, however, consumed less battery life to operate and was a more economically advantageous camera for law enforcement purposes ("Difference Between CCD and CMOS", 2000). A photographic scale was included in all photographs. All photographs were taken in the monochrome setting to prevent the loss of data in the image processing software, instead of converting the color photograph to greyscale.

Several photographs of each fabric were taken under each of the four lighting conditions. A tripod was set up above the fabric, with the camera perpendicular to the fabric surface. For each photograph the tripod was seventeen inches from the lens to the fabric. Each photograph was metered for proper exposure, with considerations made for depth of field. Several photographs were exposed for each light source and fabric. As the researcher exposed the photograph, an observation was made that the camera's choice for best exposure was oftentimes slightly different than what the researcher observed in person. After each iteration of photographs were taken, the researcher went through each photograph and designated which photograph the camera related was best exposed, and which photograph most closely represented what the researcher observed with unaided eyes.

Quill et al.(2007) and Ellison (2019) measured the "color" of light, or temperature, using the Kelvin scale. Each light source falls along the Kelvin scale as measured (See Figure 3). Normally, the human eye automatically adjusts to different light temperatures. To account for this natural adjustment in the camera, before each light source was changed, the researcher performed a manual white balance utilizing a blank sheet of white paper.

-Software Utilized to Analyze Stain Contrast-

ImageJ is an open source image processing program designed for scientific multidimensional images. Carlier & Delemont (2018) established a great method to objectively measure the intensity of blood chemiluminescence when subjected to certain reagents. Carlier's design took the photographs in color, then converted the image into greyscale, in order to measure the intensity. For the present research, the images were originally taken in the camera's monochrome setting to reduce any data loss if the image was to be converted from color to greyscale in the program. Once the image was opened in ImageJ, the researcher selected a 100 pixel circular area within the center of each of the three blood stains and documented the intensity value. A fourth measurement of the unstained area of each fabric was also documented. Numerical data was generated using software by measuring the intensity value of a selected area from zero (black) to 255 (white). Each photograph had four measurements: The intensity of the center of each of the three stains was calculated, as well as a measurement of an unstained area on the fabric. The intensity value of the unstained area of the fabric was subtracted from the mean intensity value for all three stains. The total provided the contrast between the stained and unstained area of each fabric and lighting combination.

Some of the stains had coagulated blood in the center of the drop site, where the blood was most concentrated. In some of the fabrics, the blood dried on the surface and became slightly flakey; under some light sources reflection occurred (i.e. nylon and sweatshirt jersey), which made the center of the stain appear bright white. In order to mitigate reflection skewing the contrast results, some of the intensity measurements could not be taken from the center of the blood stain.

Research Results

After the contrast values were calculated, a multivariate analysis of variance, an analysis of variance, and a t-test were conducted using a statistical analysis program to assist in interpreting the fluctuation between all variables of light and fabric type. Other variables such as fabric weave, natural or synthetic, and camera settings were also recorded however, this research was focused on contrast values of stained fabric only.

-"Up Front" Results from linear graphs-

All contrast values were initially put into linear graphs for each variable. The researcher observed the following phenomena:

-White fabrics with all light sources-Fleece had the highest contrast, in the sunlight for both camera and researcher, while polyester had the lowest contrast in the sunlight. Overall, the camera exposed the most consistent contrast values (linear graphs for all light sources were most parallel to each other.) The moisture wicking material had the most similar contrast in all light conditions for the camera as well as the researcher. (See Figure 4)

-Black with all light- The moisture wicking fabric in the sun had the most contrast for the camera, while denim had the most contrast in the sunlight condition for the researcher. Fleece fabric in LED had the most negative contrast for the camera, while fleece and nylon in LED had the most negative contrast for eyesight. Overall, the linear layout was more tightly packed for both the researcher and camera than the white fabrics for all light sources —there was more variability in contrast in white control than black. (See Figure 5)

-Grey with all light-Incandescent and CFL had the least contrast while sunlight had the most contrast. The researcher observed the sweatshirt jersey, wool, and moisture wicking to have similar contrast in CFL; while the camera picked up similar contrast levels in the sunlight. Wool blend had the least contrast under INC while moisture wicking had the most contrast. The camera exposed more contrast with moisture wicking in INC, while the researcher observed more contrast in the sweatshirt jersey under INC light. (See Figure 6)

-Red with all light-The least contrast was observed with nylon in LED lighting. Wool in the sunlight had the most contrast for both the camera and the researcher. The researcher observed similar contrast for all red fabric under CFL. Sweatshirt jersey and wool blend had similar contrast in INC for the camera. (See Figure 7)

-Blue with all light-The blue denim was compared with the white denim control: The researcher perceived more contrast in the sun only. LED had the least contrast. (See Figure 8)

-Patterned with all light-The camera had the most consistent exposure (tightest line groups). Rayon had the highest contrast for both camera and the researcher, however, this could have more to do with the colors sampled than the fabric pattern. The researcher observed the most contrast in rayon under LED, while INC/CFL created the most contrast for the camera. The least contrast for both was sweatshirt jersey under CFL. (See Figure 9)

-Military with all light-The Navy uniform had the least contrast out of all military samples. The researcher observed the most contrast with the sun in all but the Army uniform, which may be an outlier. Second to the white control, the Army uniform had the most contrast in INC light with the camera. The researcher observed the most contrast with the Army uniform in LED. CFL and LED had the least contrast for camera, while INC and CFL had the least contrast for the researcher. (See Figure 10)

-Each Fabric type with white control-

-Polyester (white, black, patterned)-Patterned fabric had the most consistent exposure under all light conditions for the camera. White fabric had more variable contrasts for both the observer and camera. The researcher observed less contrast in patterned fabric under INC and CFL than the camera; while the researcher saw increased negative contrast in black than the camera. (See Figure 11)

-Rayon (white, black, patterned)-The black fabric, for both the researcher and camera, had the most consistent negative contrast. LED created the most contrast for black, white, and patterned for the researcher; while INC and CFL had most contrast for patterned fabric for the camera; there was very little variance in contrast across light sources for camera. (See Figure 12)

-Nylon (white, black, red)-The camera had the most contrast for all fabric colors under CFL lighting; while the researcher observed the most contrast in CFL and Sun. INC and LED had the least contrast for both camera and the researcher. LED had the most negative contrast for both camera and the researcher. (See Figure 13)

-Cotton (white, black, patterned)-Black cotton fabric had the most consistent contrast over all light sources for both the camera and the researcher. The researcher observed more contrast in the sun for patterned fabric, while the camera had similar contrast for INC, LED, and sunlight in the patterned fabric. (See Figure 14)

-Wool (white, black, grey, red, natural white)-White blended wool saw the most contrast (blended with rayon), with the second being the natural white with the most contrast. The most consistent contrast across all light sources was from the camera. Sunlight showed the best contrast for both whites for the camera, while INC had the most contrast for the white wool blend and sun had the most contrast for natural white for the researcher. INC had the least contrast for natural white wool for the camera and the researcher. INC had the least contrast across all colors for the camera, while CFL had the least contrast for the researcher. The researcher observed similar contrasts for the red and grey wool under CFL and LED, as well as the natural white and red wool under INC. (See Figure 15)

-Denim (white, black, blue)-The researcher observed more contrast for blue and black fabric in the sun, while CFL had better contrast for all fabric colors in the camera. The most negative contrast was black LED for camera and the researcher. (See Figure 16)

-Sweatshirt jersey (white, grey, red, black, patterned)-Red, grey, and patterned sweatshirt jersey had similar contrasts for all light sources. Sunlight had the best exposures for grey, black, and patterned sweatshirt jersey. (See Figure 17)

-Fleece (white, black, patterned)-The camera captured more contrast in all light sources aside from the sun in black and patterned fabric. The researcher observed the best contrast in all types of fleece, while the camera observed the best contrast in white and patterned only. LED exposed the most negative contrast levels for both the researcher and the camera for black fleece. (See Figure 18)

-Moisture Wicking (White, black, grey, patterned)-The camera observed better or similar contrast in all but white fabric with sun. LED had the most negative contrast for black fabric for both the researcher and the camera. Patterned and white fabric had the closest similarity to contrast in all lighting conditions between camera and the researcher, grey fabric varied the most for the researcher, but black varied the most for the camera. (See Figure 19)

-**Overall Findings-**The camera had the most consistent exposures across all light sources, while the researcher's perception was inconsistent (See Figure 20). In some fabrics, the researcher could see contrast consistently better than the camera exposed (most likely due to over or underexposure)(See Figure 21). The more absorbent or natural the material, the easier the blood stain was to see. Blood on sheer polyester was invisible to the researcher, and to ensure the bloodstains were sampled properly, the fabric had to be held up to the light to see a faint outline then extrapolate that to what was seen on the camera and monitor. With some fabrics, if a stain appeared to have no contrast, the outline of the dried stain could be observed in the shadows in the perimeter of the stains (See Figure 22). If the blood stain had time to sit on the surface of the fabric, before soaking in, there was a high likelihood there would be coagulation in the center of the stain. In many light sources, this hardened shell would reflect most of the light, which created a hot spot and made the stain easier to differentiate (See Figure 23). One of the most surprising observations occurred during the photography phase of this research, which was the ability of the researcher to see stains with better contrast than the camera. This was seen primarily in sunlight conditions for patterned cotton, Navy, patterned and black fleece, black and blue denim, and grey moisture wicking. As mentioned briefly, most of the black material had negative contrast (See Figure 24).

Data Analysis and Interpretation

The original goal of this research was only to identify which indoor residential light source and fabric was best to mask simple blood stains; however, throughout this process several other factors and variables came forth which will be addressed. Some of these unforeseen variables were the effect of the camera used vs. the human eye as well as the stain appearing lighter in color than the fabric (negative contrast). These variables were illustrated using several types of charts and tables to better relate the answer to the above research questions.

A statistical analysis software program, SPSS (an IBM Corporation) was utilized to determine the best way to break down the dependent and independent variables. Significant values were defined as less than .05.

Frequencies

Out of a total of 507 overall photographs, 257 were chosen for the total contrast measurements utilized in the overall data analysis. A total of 1,028 intensity measurements were taken, which included four measurements per photograph. Fabric color/pattern was separated into the following categories: military patterned, floral patterned, black, blue, grey, red, and white. Fabric construction consisted of cotton, denim, fleece, military blend (50/50 cotton/ nylon), moisture wicking (100% polyester, or polyester/spandex blend), nylon, polyester, rayon, sweatshirt jersey (cotton/polyester), wool, and wool blend (See Table 2). Each of the 37 fabrics were photographed under four different light sources (CFL, incandescent, LED, and sunlight).

LED had the fewest images because the researcher-selected photographs and the camera's best exposure photographs were most similar. The mean contrast value between all fabrics was 48.41 (the most minimum value being -27.39 and maximum value being 135.61). See table three for the mean values between fabric colors, construction, and light source. The lowest mean value for color was black, which was -3.04. The highest mean contrast value for color occurred in the white control at 96.01. The lowest mean value for military fabric patterns was Navy at 8.824, while the highest value—or most contrast—was observed in the Army pattern at 67.70. There will be more discussion on sampling of multicolored patterned fabric later on, but the sample area for the Army uniform was taken from the light colors in the pattern, which caused an outlier. The lowest contrast value for fabric construction occurred in the nylon fabric with 25.86, while the highest contrast was observed in rayon with 74.37. The lowest mean contrast value for lighting occurred surprisingly in LED conditions with 44.67, while the highest mean contrast values occurred in the sun with 50.62. The mean value for the camera's best exposure was 55.63, while the mean contrast value for researcher-selected photographs was 46.55 (See Table 3).

Descriptives

Box plots seen in Figures 25 through 27 show fleece and rayon had the greatest variation, while the military uniforms, the moisture wicking material, and sweatshirt jersey had the least variability in mean contrast values. More surprisingly, we begin to see in the residential lighting box plots, indoor lighting does not have a significant impact on contrast with bloody fabric.

Multi-factor ANOVA

A Multi-Factor ANOVA (MANOVA) was initially conducted, in order to start with the bigger picture of all variables working together to create the contrast differences. Fabric color had a p-value of 0.000 and fabric construction 0.008, which supported the hypothesis. The light p-value was 0.263, as predicted from the previous descriptives. Camera vs. researcher contrast p-value was 0.239, which was further explored in the following T-Test and ANOVA (See Table 4).

T-Test

An independent samples t-test was conducted between the photographs designated as the most properly exposed, according to the camera, and the photographs chosen to best represent what the researcher observed in person. The test determined the difference between the photographs was not significant (p-value .250). A two tailed t-test was done, which provided a p-value of .121 (camera and researcher have different contrast values), which was not significant. If a one-tailed test was conducted, however, (the camera could visualize more contrast only), the p-value was .0605, which was actually slightly more significant, but the hypothesis would be rejected and the null hypothesis accepted (See table 5).

ANOVA

An ANOVA was conducted for fabric color/pattern, fabric construction, lighting, and camera vs. researcher. The results for the color/pattern test indicated there was a significant difference (p-value of .000), which supported the hypothesis. The results for the test between contrast and construction related there was also a significant difference in the construction of the fabric (p-value .012). The test between contrast and light indicated there was not a significant difference in the contrasts when viewing stains under different light conditions, which gave a p-value of .881. This was expected after the descriptive statistics box plots showed means and quartiles that were very similar across all light sources tested. Finally, the ANOVA test between camera and researcher contrast values indicated there was a significant difference (p value .032). This was unexpected, as the previous t-test indicated there was not a significant difference. Due to different degrees of freedom between the t-test and ANOVA, it was thought with more data, the camera and researcher photographs would be significant. The researcher's overall observations differed, however, because one can plainly see there were significant differences between sunlight with the camera exposure, and what the researcher witnessed (See table 6).

Discussion

Fabric color and construction are the variables which had the highest impact on contrast. Rayon had the highest mean contrast, while Nylon had the lowest total contrast values. Rayon is considered a "man made" cellulose fiber, created from the binding of the pulp of trees which are ground up and treated with different chemicals for binding (Black & Harris, 2020). The rayon material has increased luster characteristics, which lends to an elevated "glossy" look, and could be the reasoning behind the higher contrast values. This adaptable fiber can imitate the feel of cotton, silk, and other linens and can be dyed thousands of colors (Kumar, 2018). Nylon, on the other hand, is wholly a synthetic material, created by a chemical reaction from carbon-based substances. The yarn created from the chemical processes is very thin and extremely strong, lending to its versatility because it is so strong and lightweight, as seen in tooth brush bristles and parachutes. It is also water-proof and dries quickly ("Science of Synthetic Textiles", 2019). Military uniform fabrics and parachutes are made from ripstop (50/50 cotton/nylon blend), which prevents tears from running throughout the entire fabric. In this study, all military samples were comprised of 50% cotton, and 50% nylon. Nylon could have the least contrast due to its low absorbency, and Lyons and Scheier (1964) further suggested the manufacturer of the nylon could use an additive. The additive, titanium dioxide, would coat the cavities of the fibers and cause light to be transmitted at random angles, thus masking or "delustering" the fibers (Lyons and Scheier, 1964). For this research, the delustering effect was complete postulation, as none of the nylon samples were tested for titanium dioxide for confirmation.

Let's look back at the original questions which this research sought to answer and apply the researcher's observations and the statistical analysis:

Q1. What residential lighting will best mask human blood stains on apparel fabric?

LED lighting created the least contrast, with incandescent as the follow up with the least contrast. The difference between all light sources was not statistically significant, though the researcher personally observed certain nuances in the darker fabrics, (e.g. sun created shadows, negative contrast) under different conditions, which could elicit the investigator to collect as evidence.

Q2. Which color or patterned fabric will best mask a blood stain?

Solid black fabric had the least contrast, however, many of the black fabrics created a brighter stain (or negative contrast value), which was sometimes easier to observe. Black polyester fabric remained the only sample where the researcher observed no contrast at all for all light sources. This proved almost impossible to measure. The next fabric color/pattern with the least contrast was the Navy military fabric, which was comprised of dark blue and grey digi-cam. After the Navy uniform, the next fabrics with the least contrast values were grey and red, respectively.

Q3. Will patterned fabric be harder to distinguish blood stains than solid black fabric?

This question was unable to be answered due to the nature of the research design. This will be further discussed in the limitations, as well as a way forward for further investigation. Certainly it will be ascertained that different types of blood stains will be affected by patterned fabric (especially >1mm spatter vs. large drip or pattern transfers). It is interesting to note, however, patterned rayon fabric had the most contrast, which was similar to its solid rayon counterpart. The patterned sweatshirt jersey had the least contrast, however, because there was no sample of patterned nylon available, it cannot be assumed the nylon would have been less.

Q4. Which military fabric will best disguise blood in residential lighting?

The Navy uniform had the least contrast, while the Army uniform had the most contrast. The Army fabric sample may have been skewed, as the blood was dropped onto one of the lightest colors on the sample, therefore the unstained sample had to be taken from another lighter area. This alone could have skewed the Army results to seem brighter than it actually was. Most would agree the Army uniform appeared darker than the Air Force uniform fabric.

Q5. Will a digital SLR camera expose blood stains better than the human eye?

When all the variables were analyzed together in a multivariate analysis, the camera and researcher values were not significant, however, when all variables were separated from the each other, the camera/researcher variable became increasingly more significant. As mentioned previously, the camera exposed greater contrast overall, however, this does not assist the investigator on scene if the camera is not utilized to discover the stained item. At this point, as higher powered camera sensors are used on scene the significance between the human eye and the camera will intensify. Graphically speaking, the camera had less variance in contrast amongst the different light sources. Also, the difference between the mean contrast values of the camera and the researcher was 9.075, which was actually slightly greater than the contrast of the Navy uniform, which could be the difference between noticing the stained article on scene or passing it by.

Limitations

Many researchers who concern themselves with BPA must resign themselves to major limitations. At the outset of this study, great lengths were taken to reduce many limitations referenced in other articles. This research was limited by the following: Fabric dye analysis was not calculated, so the specific dye or shade of color could not be determined or be consistent for each fabric. This would have undoubtedly changed the contrast values, especially for the patterned fabrics, as samples were taken where multiple colors were present; however, the colors measured were inconsistent. A second limitation would be the floral patterns were not the same across all fabric constructions. An attempt to mitigate this issue was made by trying to measure a larger area, to include one repeating flower pattern per fabric. This attempt was annulled when it was soon realized the contrast values for all patterns would differ due to the different colors and sizes of the flower patterns.

Another limitation was the introduction of fabric blends to this study. The research centered on available fabrics at a local fabric supplier, however, the original list of apparel fabrics called for very common types of clothing (e.g. moisture wicking), and some of these were not available at the fabric supplier. The researcher felt this type of fabric was too common in American culture not to include, so a trip to retail outlets ensured the sample would be present. This ultimately would include some blends, however, all attempts were made to ensure the blends of each color/pattern remained as consistent as possible.

De Castro (2013 and 2015) and Li (2017) exhaust the importance of fabric weave and its effect on blood wicking and shape of stain. This study focused primarily on the contrast of blood and unstained fabric, so this did not play an integral part; however, each sample was recorded to be either woven, knit, or pilled. All stains were measured in the approximate center of the stain, so the difference the weave of the fabric had should not have effected the contrast values. One area this could be observed in was the difference between the wool fabrics and the polyester samples. The fibers of the wool samples were still visible, whereas the blood wicked out on the polyester fabric (see Figure 28). Another limitation of the wool fabric samples was that they were not washed. Originally, the samples were washed, however, because wool is not woven together, it is pressed together, washing the wool caused the samples to fall apart. This made the samples impossible to drop blood on, so none of the wool samples were laundered prior to any blood deposited. With this in mind, the researcher was unaware if the chemicals and starches had any effect on the contrast of the wooled fabrics; however, this could have been the cause of the blood drying on the surface of the sample and not absorbing.

There were also several limitations surrounding the camera utilized in this experiment. One, while photographing the samples, the researcher went back through each series on the 3.2" digital display for the researcher's selection. This display would have compressed every photograph; however, this was done in the interest of time, as well as mobility. The photograph on screen was compared to exactly what the researcher observed in person under each light source, instead of going back and forth between the room in which the light source and sample were located and a large computer display. Also, the camera sensor itself was at least five years old, and would have degraded slightly over time. This fact was not able to be measured, but must be taken into consideration. This camera does have the capability of high dynamic range (HDR) photography, however, the images were not processed in any program that would account for this. Finally, only one researcher compared the metered photographs to choose the photograph that looked best to what was observed "on scene." Adding more researchers would have provided more data points to ensure the difference between the camera's best exposure and the researcher was as significant as it appeared.

Future Research

Many of the limitations can be extrapolated into future research concerning apparel fabric and blood intensity levels. This research design will allow further studies including different types of stains, more blended fabrics, more solid colors, more light sources, and more researchers (for camera vs. researcher comparison). Also, an entirely separate study should be completed on patterned fabrics, which would print the same pattern on all types of fabric for consistency. Finally, it would be advantageous for future research to identify which type of flashlight, which all crime scene investigators should possess, would best aid in searching for "vanishing" blood stains on apparel fabric.

Conclusion

All black fabrics exhibited negative contrast under one or more light sources. The most extreme negative contrast values were observed in nylon and fleece. The explanation for this contrast could be the blood absorbed light in alternate light source situations, however, this study clearly shows blood does not absorb as much light as the black background in non-ALS conditions, which made it appear lighter in color. Another explanation for the two manufactured fabrics to have the most negative contrasts could be the blood was sitting on top of the fibers, where it dried, and ultimately reflected the light source, while the black fabric underneath continued to absorb the light.

Ultimately, the homicide detective will be able to take away certain facts from this research. Blood on black fabric will be the most difficult to view, however, certain light sources and conditions (sun/shadow) can be utilized to determine if the item is of evidentiary value if no ALS is available. Additionally, it is important to note that a camera will most often assist in the exposure, however, an average person will not see exactly what the camera records. And finally, most common household light sources do not significantly affect contrast; however, certain fabrics will be easier to observe contrast on than others. For the eye witness, statements could be verified or refuted, at least in reference to whether or not they saw potential blood on black sheer polyester fabric. Furthermore, for the laboratory technician who received potential blood evidence on clothing, this research will assist their understanding of why they may or may not be able to see what the officer on scene could or could not see. This is especially true if the lab utilized primarily LED overhead lighting. This study will also help the technician to understand which fabrics will most likely need to immediately be looked at under ALS.

It has been 138 years since the primary source of lighting was by candle or lantern. The recent shift to more energy efficient indoor lighting has second and third order effects, especially within the law enforcement and scientific community. Exploring a method to quantify how intense a bloodstain will be on certain fabrics in different situations will open the door to the identification of more evidence at a scene. This project provided the basis to understand what the effect of white light had or did not have on blood and apparel fabrics.

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Table 1. Fabric List

Fabric Sample Breakdown

Sample Number	Fabric Make-up	Weave (Knit/Woven)	Color/Pattern
1	**Polyester (100%)**	**Woven**	White
2	**Polyester (100%)**	**Woven**	Black
3	**97% polyester, 3% spandex**	**Woven**	Multi-colored floral
4	**Rayon (95% Rayon, 5% spandex)**	**Woven**	White
5	**Rayon (100%)**	**Woven**	Black
6	**Rayon (100%)**	**Woven**	Multi-colored floral
7	**Nylon (100%)**	**Woven**	White
8	**Nylon (100%)**	**Woven**	Black
9	**Nylon (100%)**	**Woven**	Red
10	**Cotton (100%)**	**Woven**	White
11	**Cotton (100%)**	**Woven**	Black
12	**Cotton (100%)**	**Woven**	Multi-colored floral
13	**Wool (35% wool, 65% rayon)**	**Non-woven**	White
14	**Wool (35% wool, 65% rayon)**	**Non-woven**	Black
15	**Wool (35% wool, 65% rayon)**	**Non-woven**	Grey
16	**Wool (35% wool, 65% rayon)**	**Non-woven**	Red
17	**Wool (100%)**	**Non-woven**	Off-white
18	**Denim (100% Cotton)**	**Twill**	White
19	**Denim (99% Cotton, 1% spandex)**	**Twill**	Black
20	**Denim (100% Cotton)**	**Twill**	Blue
21	**Sweatshirt Jersey (58% cotton, 42% Polyester)**	**Woven**	White
22	**Sweatshirt Jersey (60% cotton, 40% polyester)**	**Woven**	Black
23	**Sweatshirt Jersey (85% polyester, 15% cotton)**	**Woven**	Grey
24	**Sweatshirt Jersey (60% cotton, 40% polyester)**	**Woven**	Red
25	**Sweatshirt Jersey (60% cotton, 40% polyester)**	**Woven**	Multi-colored floral
26	**Fleece (100% Polyester)**	**Non-woven/Napped**	White
27	**Fleece (100% Polyester)**	**Non-woven/Napped**	Black
28	**Fleece (100% Polyester)**	**Non-woven/Pile**	Multi-colored floral
29	**Moisture Wicking (100% Polyester)**	**Woven**	White
30	**Moisture Wicking (90% polyester, 10% spandex)**	**Woven**	Black
31	**Moisture Wicking (92% polyester, 8% spandex)**	**Woven**	Grey
32	**Moisture Wicking (96% Polyester, 4% spandex)**	**Woven**	Multi-colored floral
33	**50% Nylon/50% Cotton**	**Woven**	White
34	**50% Nylon/50% Cotton**	**Woven**	Army Multicam
35	**50% Nylon/50% Cotton**	**Woven**	Marine Combat Utility Uniform
36	**50% Nylon/50% Cotton**	**Woven**	Navy Working Uniform
37	**50% Nylon/50% Cotton**	**Woven**	Airman Battle Uniform
	37 Samples		

Table 2. Frequencies

Fabric Color

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Air Patterned	7	2.7	2.7	2.7
	Army Patterned	6	2.3	2.3	5.1
	Marine Patterned	6	2.3	2.3	7.4
	Navy Patterned	7	2.7	2.7	10.1
	Patterned	41	16.0	16.0	26.1
	Solid black	60	23.3	23.3	49.4
	Solid blue	7	2.7	2.7	52.1
	Solid gray	22	8.6	8.6	60.7
	Solid red	22	8.6	8.6	69.3
	Solid white	79	30.7	30.7	100.0
	Total	257	100.0	100.0	

Fabric Construction

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Cot	23	8.9	8.9	8.9
	Den	21	8.2	8.2	17.1
	Fle	21	8.2	8.2	25.3
	Mil	32	12.5	12.5	37.7
	Moi	27	10.5	10.5	48.2
	Nyl	22	8.6	8.6	56.8
	Poly	20	7.8	7.8	64.6
	Ray	21	8.2	8.2	72.8
	Swe	35	13.6	13.6	86.4
	Wool	35	13.6	13.6	100.0
	Total	257	100.0	100.0	

Light

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	CFL	64	24.9	24.9	24.9
	INC	64	24.9	24.9	49.8
	LED	55	21.4	21.4	71.2
	Sun	74	28.8	28.8	100.0
	Total	257	100.0	100.0	

Table 3. Compare Means

Fabric Color

Contrast

FabricColor	Mean	N	Std. Deviation
Air Patterned	44.6016190	7	4.76509150
Army Patterned	67.7030556	6	23.8412276
Marine Patterned	34.5602222	6	9.90385058
Navy Patterned	8.82419048	7	4.85698205
Patterned	66.4920244	41	26.1212210
Solid black	-3.0399000	60	8.41314388
Solid blue	19.3219048	7	8.75402974
Solid gray	27.3317576	22	8.57236075
Solid red	26.7380303	22	13.8818965
Solid white	96.0115570	79	23.0278506
Total	48.4087198	257	43.0394798

Fabric Construction

Contrast

FabricConstruction	Mean	N	Std. Deviation
Cot	61.3367391	23	43.7507219
Den	37.1914762	21	43.7326930
Fle	53.9170794	21	55.9918189
Mil	49.5707396	32	33.3400769
Moi	51.0153704	27	32.3395218
Nyl	25.8641061	22	36.8466894
Poly	34.0227833	20	29.2679649
Ray	74.3738730	21	56.0706283
Swe	43.0656476	35	41.3835745
Wool	52.4206476	35	43.7958501
Total	48.4087198	257	43.0394798

Light

Contrast

Light	Mean	N	Std. Deviation
CFL	49.6279167	64	43.4504147
INC	47.8458906	64	40.4689850
LED	44.6702000	55	47.2264371
Sun	50.6196802	74	42.2665872
Total	48.4087198	257	43.0394798

Table 4. Multi-Factor Analysis of Variance

MANOVA

Tests of Between-Subjects Effects

Dependent Variable: Contrast

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Powerb
Corrected Model	470581.905a	247	1905.190	4.721	0.007	1166.192	0.973
Intercept	199938.986	1	199938.986	495.487	0.000	495.487	1.000
FabricColor	205412.959	9	22823.662	56.561	0.000	509.053	1.000
FabricConstruction	20852.453	9	2316.939	5.742	0.008	51.676	0.943
Light	1902.756	3	634.252	1.572	0.263	4.715	0.285
CameraEyesight	1357.833	2	678.916	1.682	0.239	3.365	0.266
Color * Construction	22447.978	17	1320.469	3.272	0.037	55.630	0.795
Color * Light	1144.649	20	57.232	0.142	1.000	2.837	0.073
Color * CameraEyesight	1404.175	9	156.019	0.387	0.913	3.480	0.114
Construction * Light	3088.083	25	123.523	0.306	0.991	7.653	0.106
Construction * CameraEyesight	287.080	9	31.898	0.079	1.000	0.711	0.062
Light * CameraEyesight	476.642	3	158.881	0.394	0.761	1.181	0.101
Color * Construction * Light	2666.559	20	133.328	0.330	0.981	6.608	0.110
Color * Construction * CameraEyesight	644.504	17	37.912	0.094	1.000	1.597	0.065
Color * Light * CameraEyesight	746.658	18	41.481	0.103	1.000	1.850	0.066
Construction * Light * CameraEyesight	477.338	23	20.754	0.051	1.000	1.183	0.058
Color * Construction * Light * CameraEyesight	687.805	19	36.200	0.090	1.000	1.705	0.064
Error	3631.681	9	403.520				
Total	1076468.454	257					
Corrected Total	474213.586	256					

a R Squared = .992 (Adjusted R Squared = .782)

b Computed using alpha = .05

Table 5. Independent Sample T-Test

Independent Sample T-Test

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	**Sig.**	**t**	**df**	**Sig. (2-tailed)**	**Mean Difference**	**Std. Error Difference**	**95% Confidence Interval of the Difference**	
									Lower	Upper
Contrast	Equal variances assumed	1.332	0.250	1.558	211	0.121	9.074	5.825	-2.408	20.557
	Equal variances not assumed			1.555	207.663	0.121	9.074	5.836	-2.431	20.579

Table 6. Analysis of Variance

			Sum of Squares	df	Mean Square	F	Sig.
Color and Pattern	Between Groups	(Combined)	391722.722	9	43524.747	130.325	0.000
	Within Groups		82490.863	247	333.971		
	Total		474213.586	256			

			Sum of Squares	df	Mean Square	F	Sig.
Construction	Between Groups	(Combined)	38391.606	9	4265.734	2.418	0.012
	Within Groups		435821.979	247	1764.461		
	Total		474213.586	256			

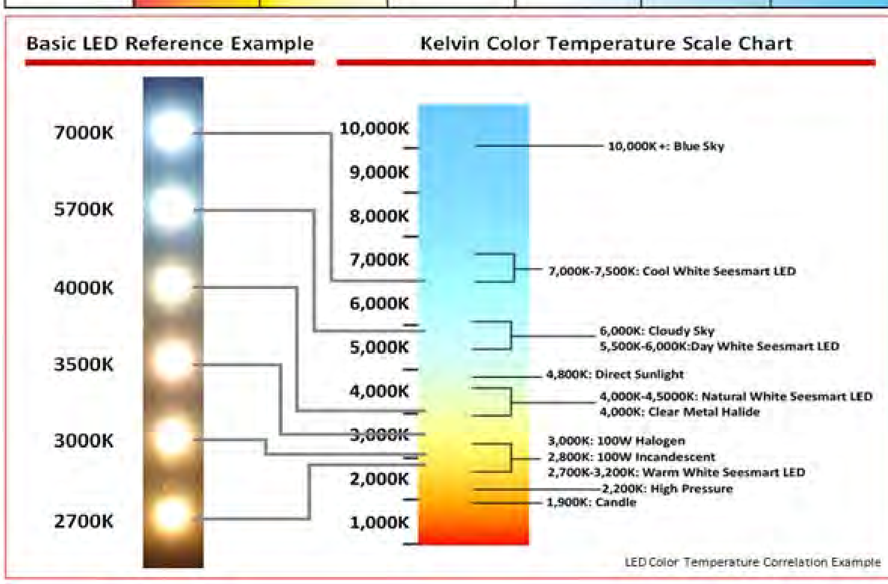
			Sum of Squares	df	Mean Square	F	Sig.
Light	Between Groups	(Combined)	1245.853	3	415.284	0.222	0.881
	Within Groups		472967.733	253	1869.438		
	Total		474213.586	256			

			Sum of Squares	df	Mean Square	F	Sig.
Camera vs. Researcher	Between Groups	(Combined)	12626.058	2	6313.029	3.474	0.032
	Within Groups		461587.527	254	1817.274		
	Total		474213.586	256			

Figure 1. ***Blood Deposit Mechanism***

Figure 3. ***Color Temperature Scale***

Kelvin Color Temperature	2700K	3000K	3500K	4100K	5000K	6500K
Associated Effects and Moods	Ambiant Intimate Personal	Calm Warm	Friendly Inviting	Precise Clean Efficient	Daylight Vibrant	Daylight Alert
Appropriate Applications	Living/Family Rooms Commercial/ Hospitality	Living/Family Rooms Commercial/ Hospitality	Kitchen/Bath Light Commercial	Garage Commercial	Commercial Industrial Institutional	Commercial Industrial Institutional



Note: Data for light color temperature from Ellison (2019)

Figure 4. *White Fabric Linear Graphs*

Figure 5. *Black Fabric Linear Graphs*

Figure 6. *Grey Fabric Linear Graphs*

Figure 7. *Red Fabric Linear Graphs*

Figure 8. *Blue Fabric Linear Graphs*

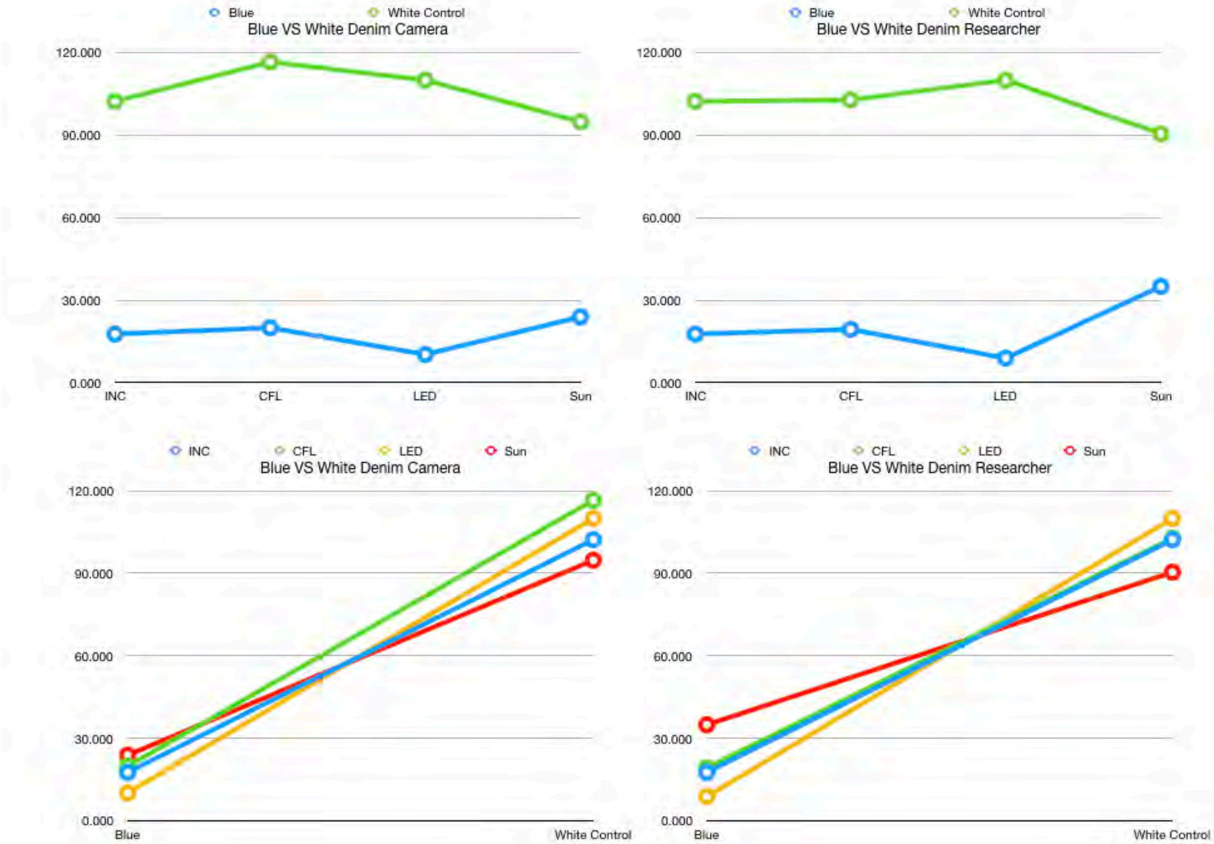


Figure 9. *Patterned Fabric Linear Graphs*

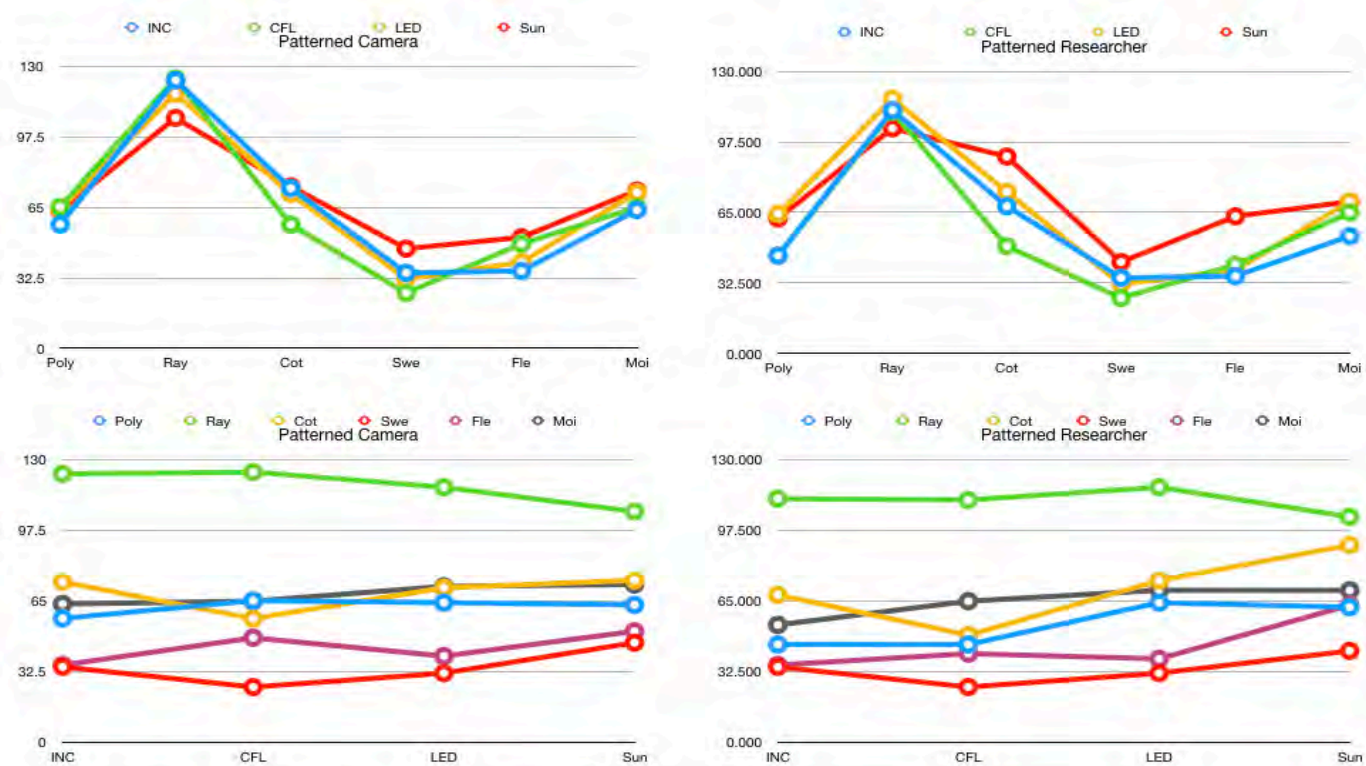


Figure 10. *Military Fabric Linear Graphs*

Figure 11. *Polyester Fabric Linear Graphs*

Figure 12. *Rayon Fabric Linear Graphs*

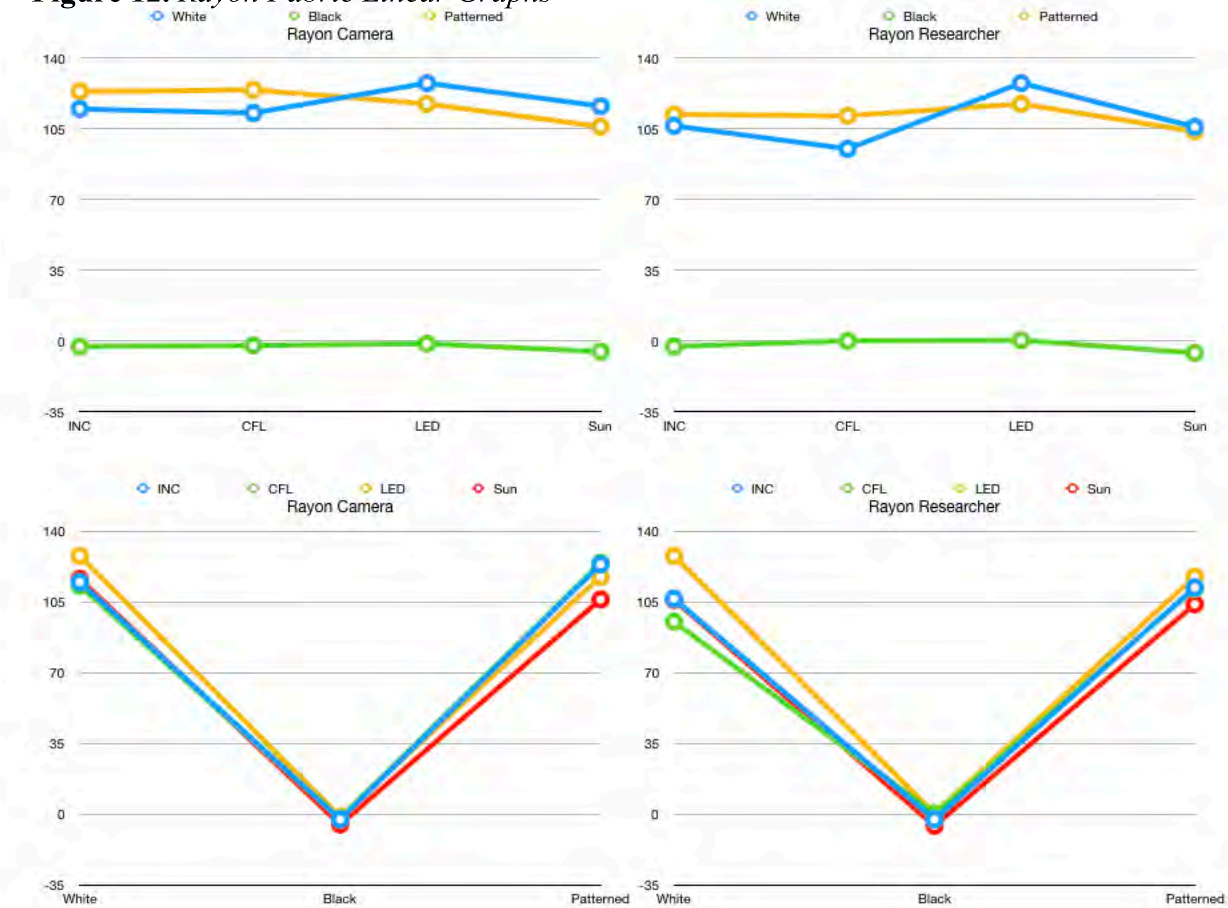


Figure 13. *Nylon Fabric Linear Graphs*

Figure 14. *Cotton Fabric Linear Graphs*

Figure 15. *Wool Fabric Linear Graphs*

Figure 16. *Denim Linear Graphs*

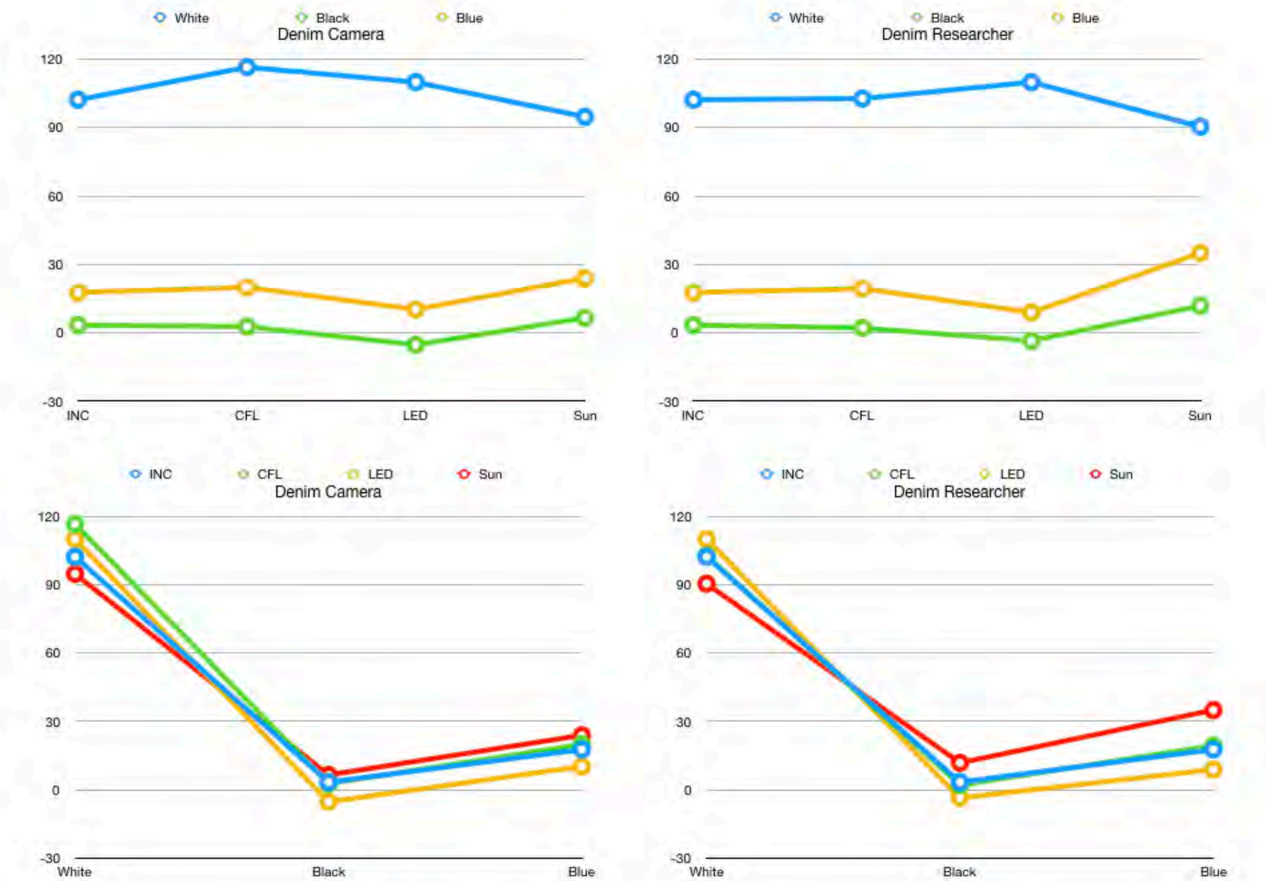


Figure 17. *Sweatshirt Jersey Linear Graphs*

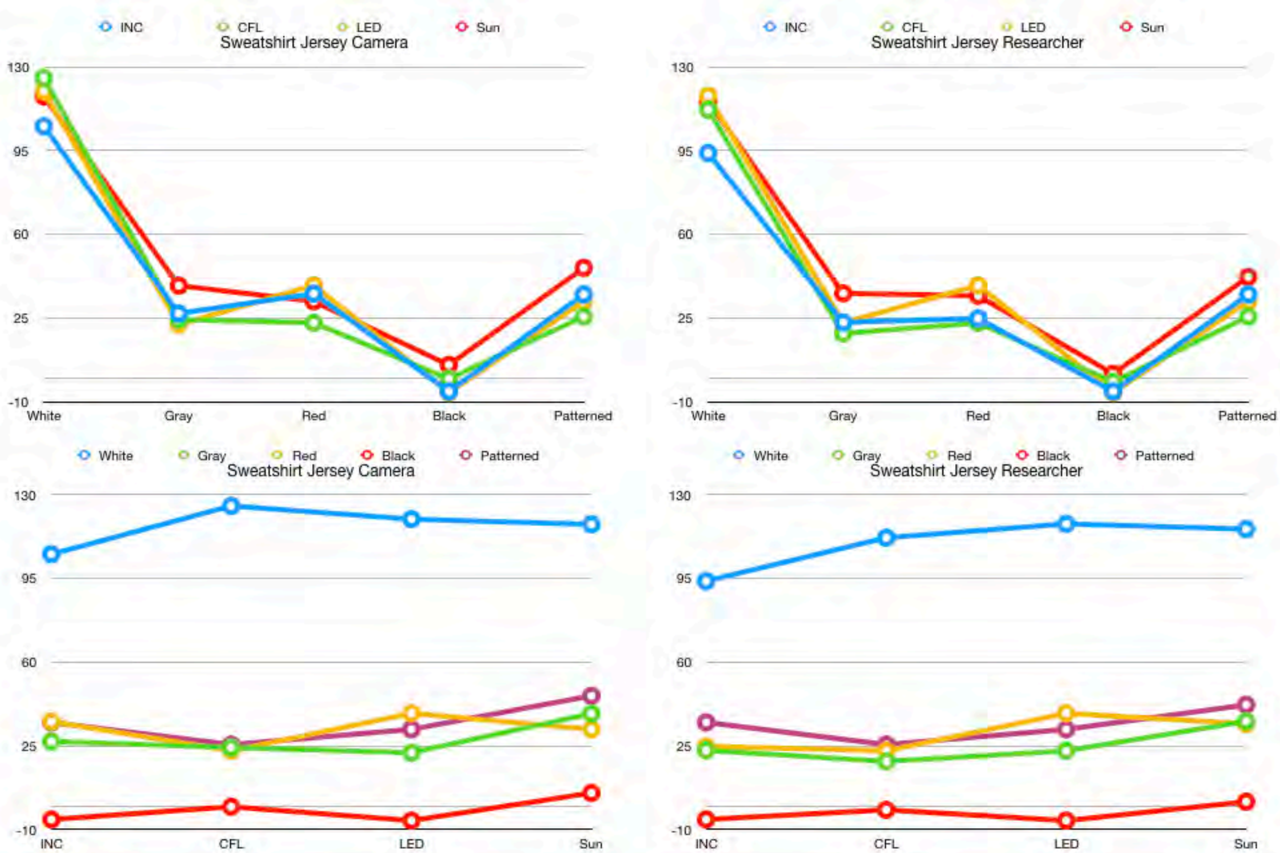


Figure 18. *Fleece Linear Graphs*

Figure 19. *Moisture Wicking Linear Graphs*

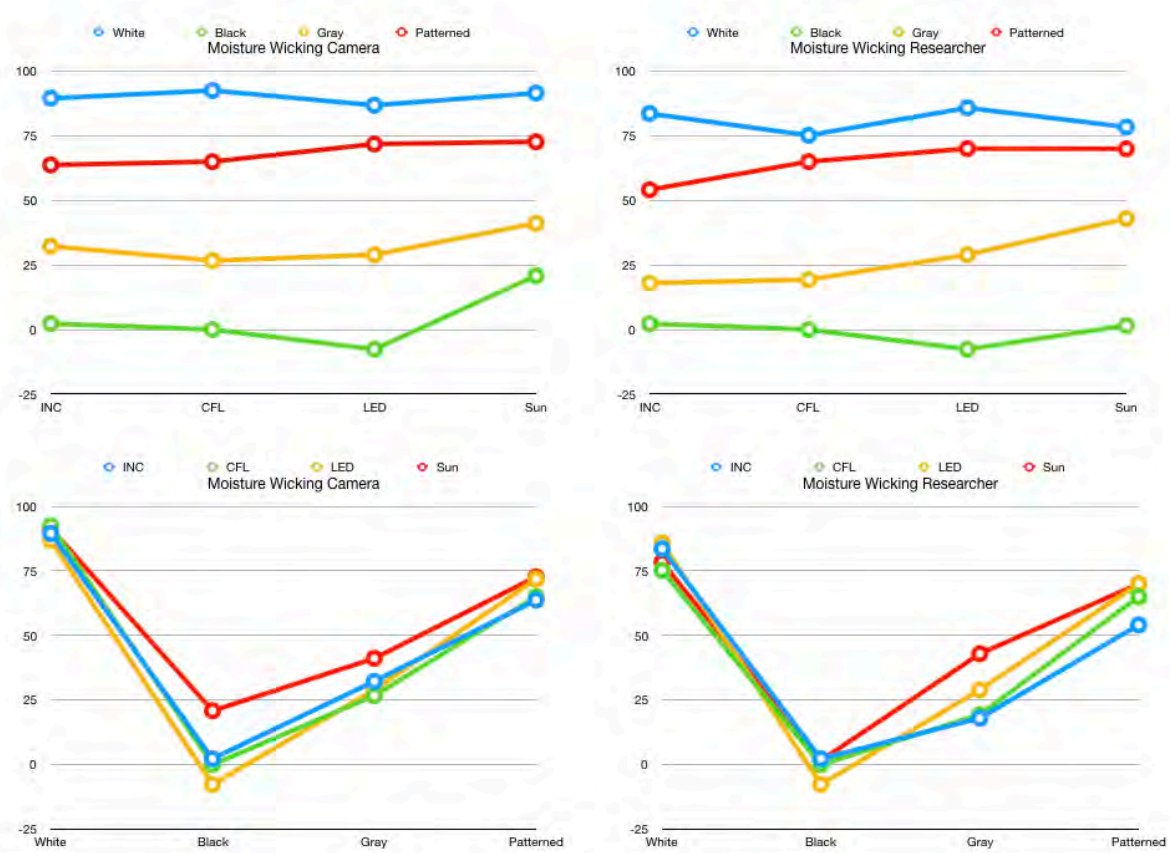
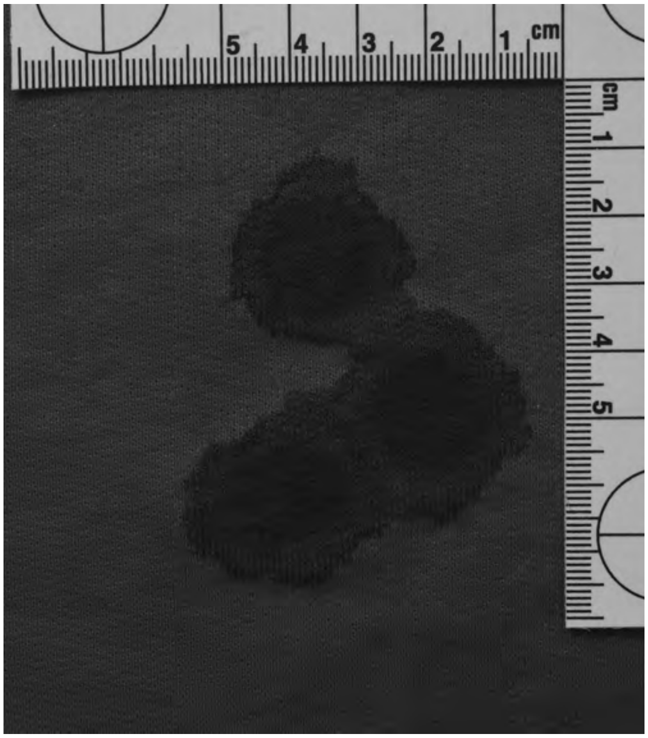
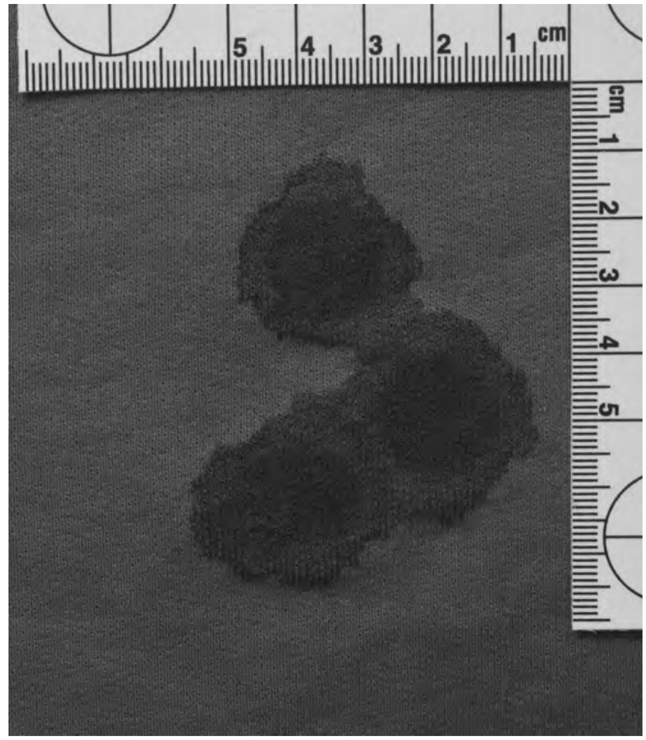


Figure 20. Red Sweatshirt Jersey in Incandescent Light, Camera vs. Researcher

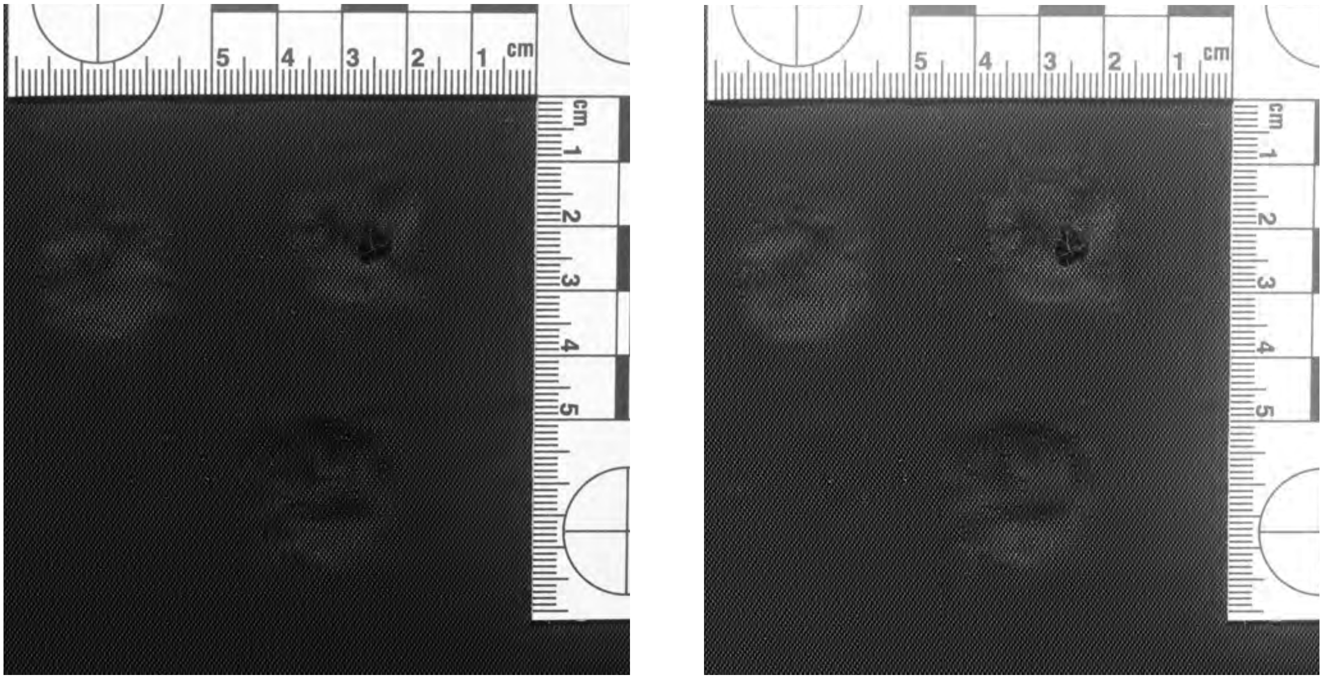


NC Red Sweatshirt Jersey (Researcher)



NC Red Sweatshirt Jersey (Camera)

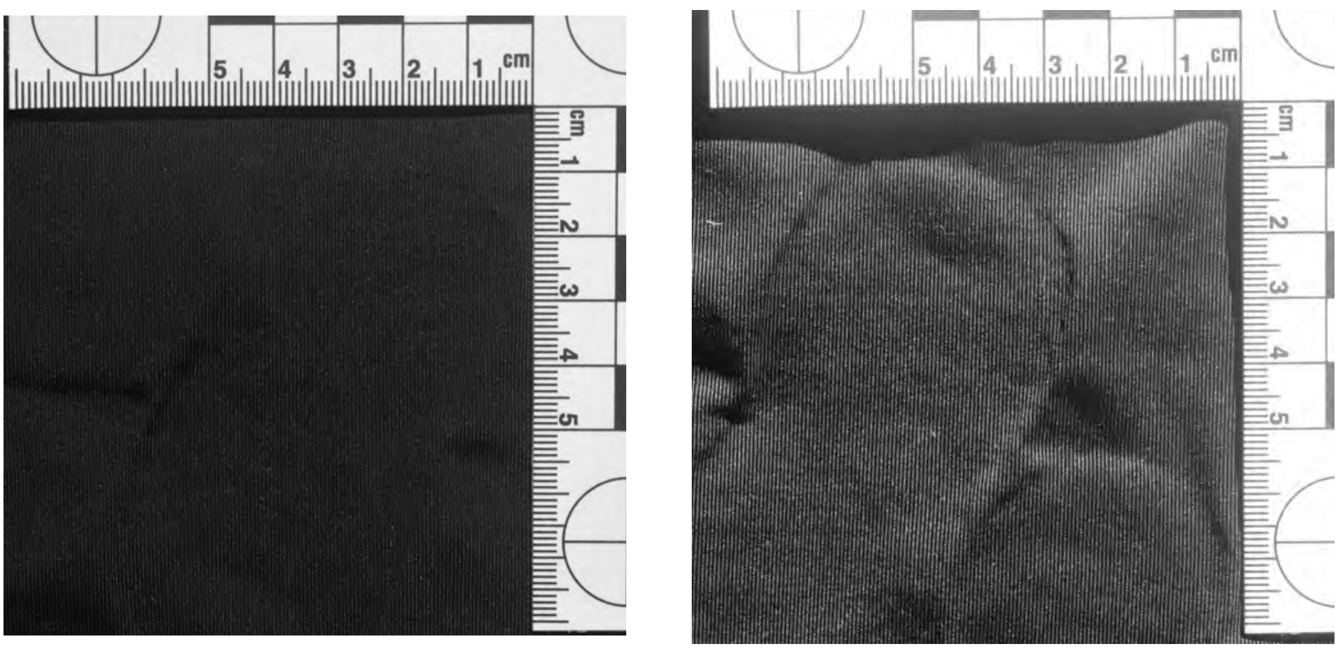
Figure 21. Black Nylon in Sunlight, Camera vs. Researcher



Black Nyl Sun (Camera)

Black Nyl Sun (Researcher)

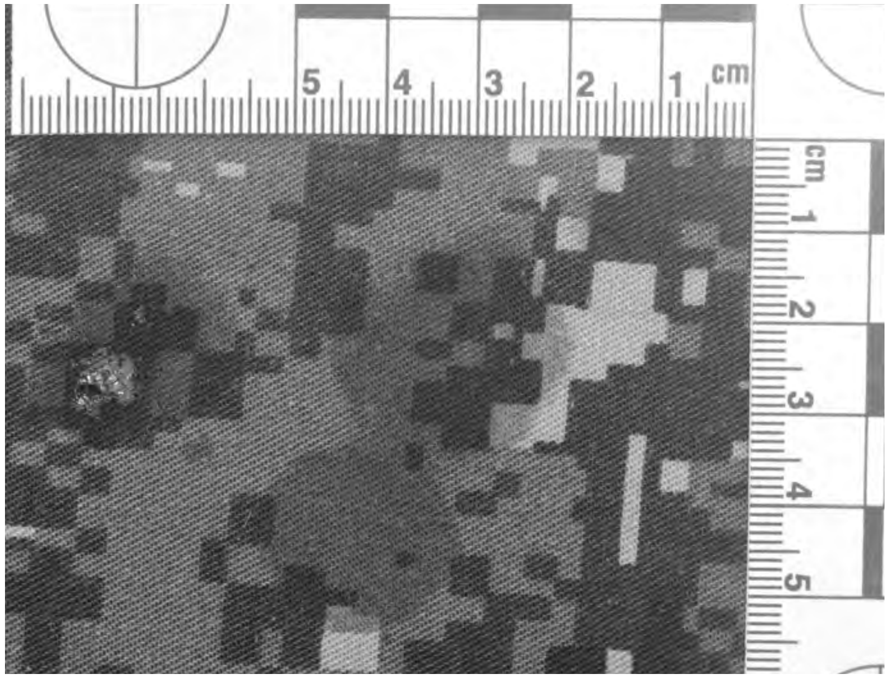
Figure 22. Black Moisture Wicking Stain Shadow



Black Moi L D

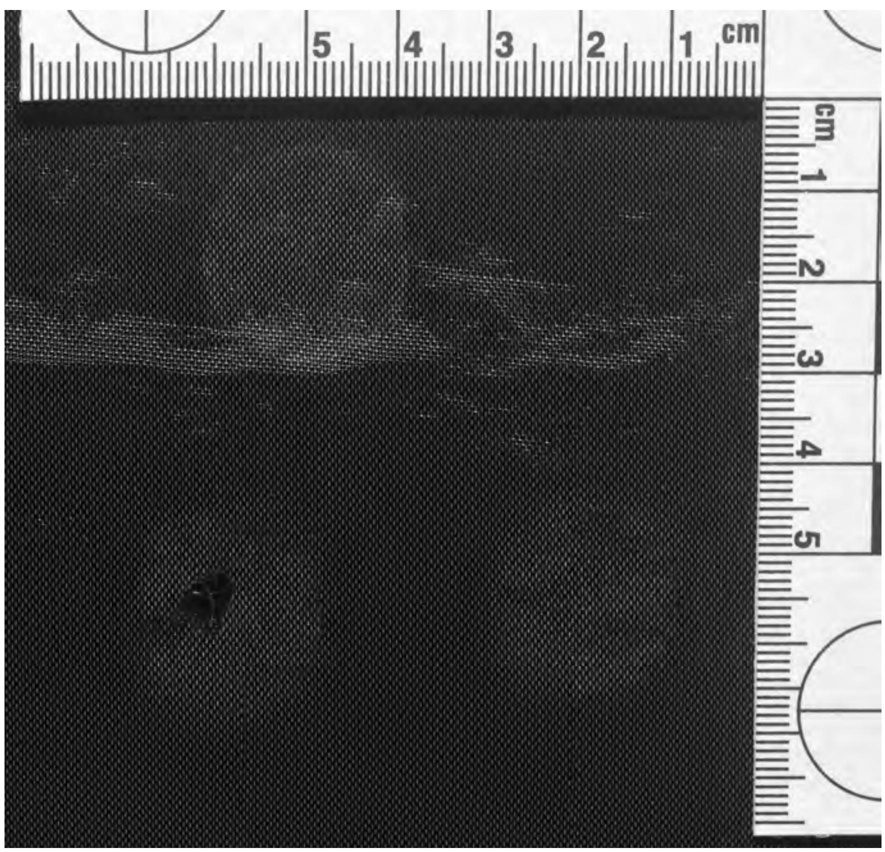
Black Moi Sun

Figure 23. Blood Hot Spot



CFL Navy (Hot Spot)

Figure 24. Negative Contrast



Black Nyl Sun (Negative Contrast)

Figure 25. *Box Plot Represent Fabric Construction*

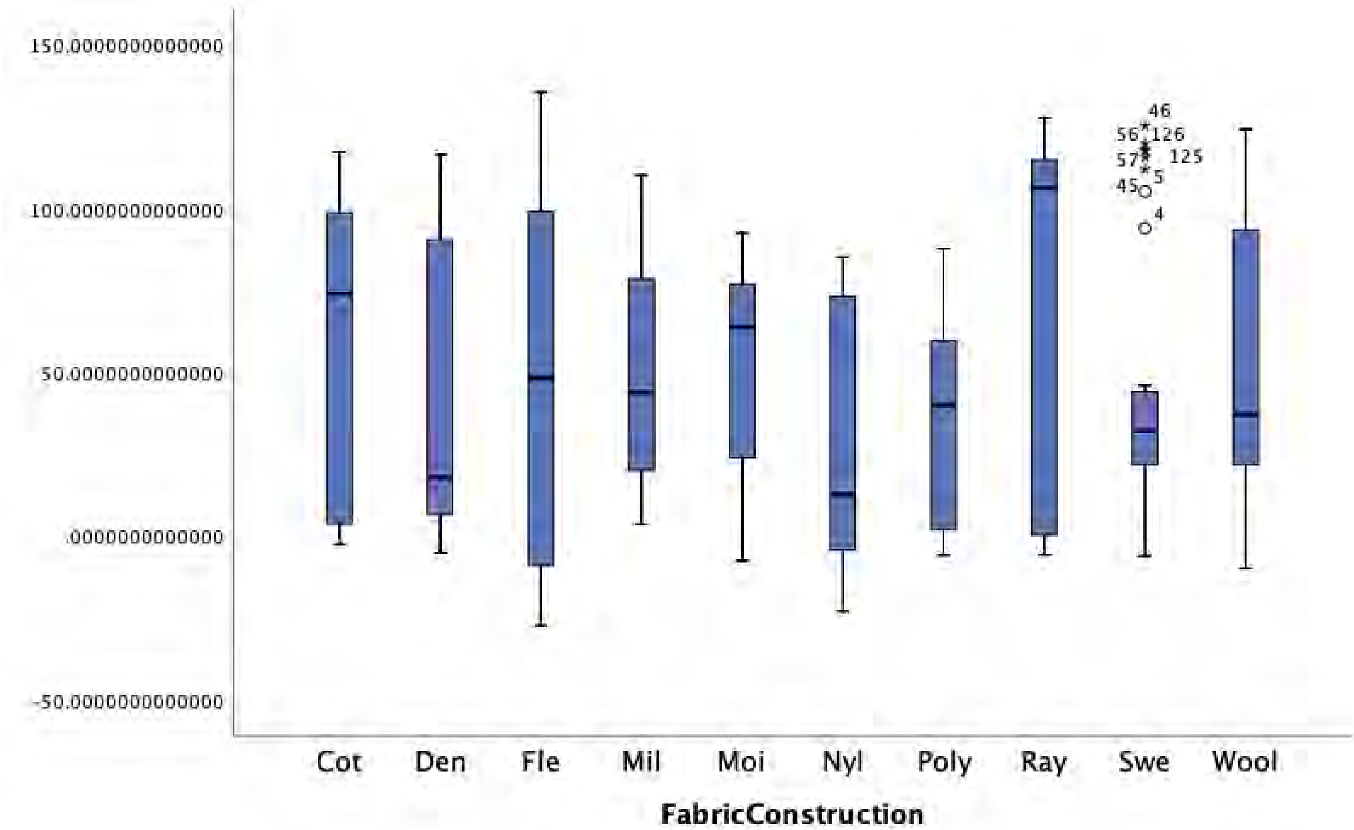


Figure 26. *Box Plot Representing Fabric Color/Pattern*

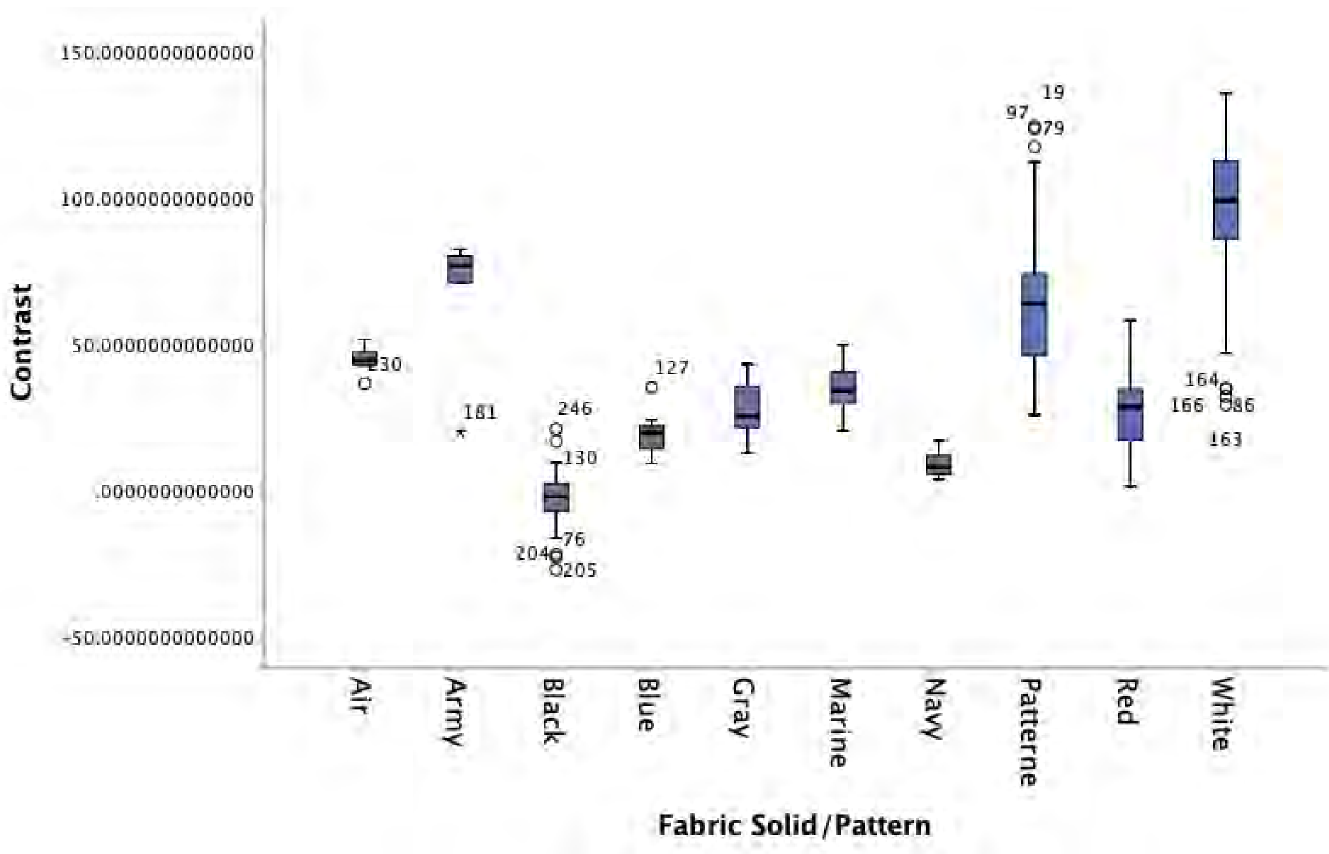


Figure 27. Box Plots Representing Light Sources

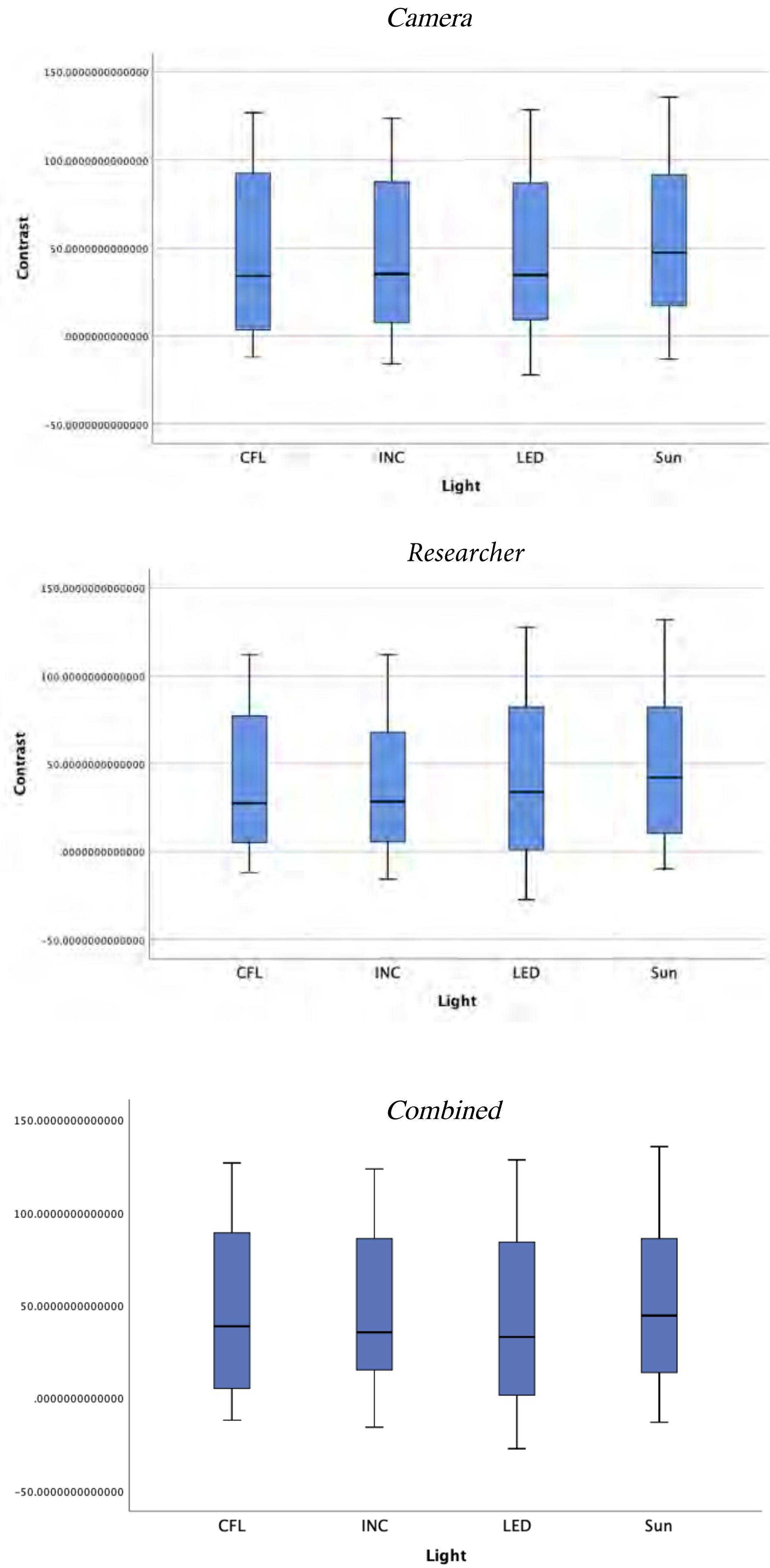
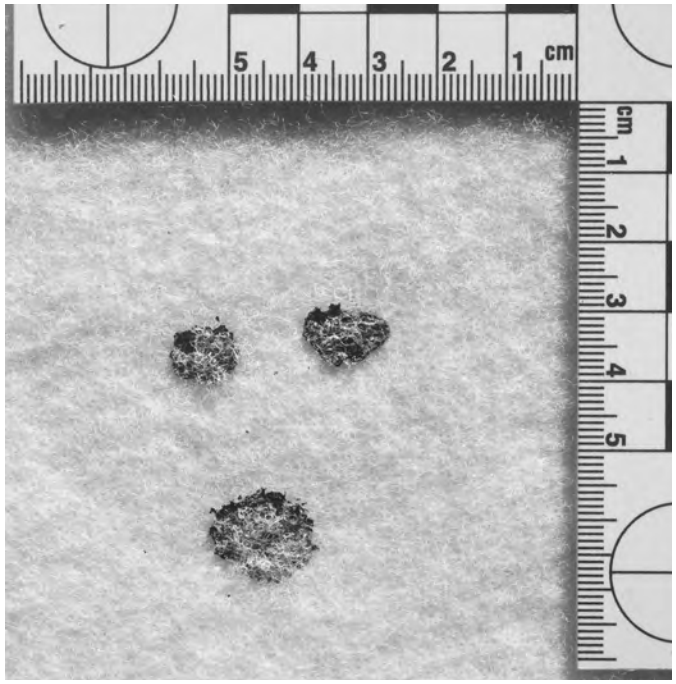


Figure 28.



White Wool (Natural) vs. White Polyester (Synthetic)